Semi-Annual Report
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Entitled:

REMOTE SENSING OF GLOBAL SNOWPACK ENERGY AND MASS BALANCE:

IN-SITU MEASUREMENTS ON THE SNOW OF INTERIOR AND ARCTIC ALASKA

Submitted by

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INTRODUCTION

This project is continuing along the lines of the semi-annual report dated January, 1993. Four major tasks have been addressed: (1) analysis of variability in the seasonal snow of interior and arctic Alaska, (2) the interpretation of microwave brightness temperature across Alaska on transects from South to North, (3) study of non-climatic controls which affect glaciers, and (4) the location of glacier facies boundaries.

1. SEASONAL SNOW OF INTERIOR AND ARCTIC ALASKA

Detailed study of the variability of snow cover in spruce forests and on tussock tundra continued by examining data obtained over several years, including the abnormally heavy snow of the 1990-'91 and 1992-'93 winters in interior Alaska. An overview of research on Alaskan snow cover was published by Benson (1993), and a paper by Benson and Sturm (1993) summarized the structure and wind transport of snow, identified the major types of snow, and pointed out the need for mapping boundaries between the major wind regimes on Alaska's Arctic Slope

Our research on variability of Alaska seasonal snow in the interior, near Fairbanks, and on the Arctic Slope, between the Brooks Range and Prudhoe Bay, has been augmented by cooperation with Dr. Matthew Sturm's CRREL Research (U.S.A. Cold Regions Research and Engineering Laboratory) and with my R4D project in the northern foothills of the Brooks Range, supported by Department of Energy.

This sort of collaboration will continue and be expanded by including ties to three other projects:

(1) Hydrological research in the Kuparuk drainage basin which extends from the R4D area, mentioned above, to the Arctic coast near Prudhoe Bay. This research, supported by NSF, is being directed by Dr. Douglas Kane of the Water Resource Center of the University of Alaska.

(2) Snow research of the USGS in connection with studies of temperature changes as recorded in drill holes on the Arctic Slope of Alaska. This work is being done by Drs. Gary Clow and Arthur Lachenbruch.

(3) The Atmospheric Radiation Measurements (the ARM Program) of the Department of Energy on the Arctic Slope of Alaska. This is under the overall direction of Dr. Bernard Zak (DOE) and Dr. Knut Stamnes, of the Geophysical Institute, University of Alaska Fairbanks.

We have worked to maximize communication and sharing of logistics between these projects to the benefit of all of them.

2. MICROWAVE BRIGHTNESS TEMPERATURES

Our interpretation of passive microwave data began with SSMI data covering January through February 1989. The 59 daily records extend from the Pacific Ocean at 58° N, south of Alaska, to 73° N in the Arctic Ocean north of Alaska. They span the all-time low January temperatures, followed in several days by all-time high February temperatures. We selected this data set as a first case for detailed analysis because of our available information on this extreme condition. Our first approach was to plot the data in a North-South strip, at 148°00'W for dates 24, 27, and 30 January (the lowest temperatures) and 9, 12, and 13 February 1989 (the highest temperatures). The differences in brightness temperatures are marked, and for the land areas the microwave brightness temperatures were consistent with surface temperature data. Ocean areas were anomalous and must be considered separately.

Our second approach was to map three-day averages of passive microwave data, obtained between January and June 1989 for all of Alaska. These maps clearly show that factors other than snow cover, variable snow structure, and air temperature, control the microwave brightness temperature.

We have begun to investigate the role of vegetation in combination with the other factors named above. Two products have been used so far. One is the "Greenness Index of Alaska derived from satellite data, the other is the map **"Potential Natural Vegetation of Alaska"** by A. W. Küchler (sheet No. 89 in the National Atlas of the U.S., published by the U.S. Geological Survey). The latter was digitized for comparison with the Greenness Index and with the maps of passive microwave data. The role of vegetation appears to be major and offers possible explanation of some anomalies that can't be explained by considering air temperature and snow cover alone. The complex interplay between these factors was presented in a paper by Hall and others (1993).

3. PHOTOGRAMMETRY AND LANDSAT IMAGERY USED TO MEASURE CHANGES IN GLACIER SIZE

The 1993 aerial photography was successful over the summit of Mt. Wrangell. Photogrammetrical cross sections have been made and calculations of the change in ice volume within the North Crater are underway. These data are being analyzed in connection with field work extending over 30 years. The aerial photographs in 1993 were easier to work with than those of 1992 because less of the crater floor was obscured by plumes generated from fumaroles in the crater. The photogrammetry was paid (as before) by the U.S. Geological Survey and the Alaska Division of Geological and Geophysical Surveys.

A large effort recently has gone into the analysis of ice volume changes in the North Crater of Mt. Wrangell. This has been done by working with the digital data of cross sections measured photogrammetrically. Errors caused by condensed steam clouds in the crater have been corrected by plotting data from successive years on a single graph. The condensation plumes occur in different places from one year to the next, and clear areas of one year often provide data which can be used as a guide in correcting covered intervals in the following year.

Changes in the termini of tide-water glaciers have been studied by a combination of field surveying, aerial photogrammetry and satellite imagery. This is another aspect of non-climatic controls on glacier behavior. We completed studies on tide-water glaciers in the College Fjord area (Sturm and others, 1990, and 1991). A second paper on changes in the tide-water glaciers of Glacier Bay, Alaska is in preparation (Hall and others, 1994).

4. GLACIER FACIES BOUNDARIES

We have had some success in using satellite imagery to determine glacier facies boundaries. A discussion of facies boundaries that are discernible at the surface, by aerial photographs and LANDSAT imagery, was presented by Williams and others (1991). SAR offers new possibilities because it obtains data from below the surface.

Lingle and others (1993) showed that SAR makes it possible to map the upper limit of the snow line on glaciers even after new snow covers the entire glacier. This is a major breakthrough. In the past we tried to be on, or fly over, the glacier at the time when the snow line was at its maximum altitude at the end of summer. However, ground observations are restricted severely because of the vast areas involved and autumn weather frequently makes it impossible to fly in the mountains, so one cannot count on obtaining aerial photographs or cloud-free LANDSAT images. SAR images show the position of the snow (or firn) line in mid-winter through the layer of dry, seasonal snow.

SAR also obtains data from several annual units. This suggests that it may be possible to discern glacier facies boundaries that are not visible at the surface. The ability of SAR to do this was shown over Greenland by Fahnestock and others (1993). A summary of the glacier facies concept, the physical measurements required to detect them, and the application of LANDSAT and SAR imagery to the problem was presented by Benson (1994). Lingle and others (1994) show that SAR can also discern the latter glacier facies boundaries in the mountains of Alaska. Research on this application of SAR imagery will continue to receive attention.

5. BIBLIOGRAPHY AND PAPERS IN PROGRESS

Benson, C. S. 1993. An Overview of Research on Snow in Alaska, in: Snow Watch '92: Detection Strategies for Snow and Ice. World Data Center for Glaciology A, Glaciological Data Report, WDC-A GD-Report 25, p.135-143.

Benson, C. S. 1994. Glacier Facies: With Special Reference to Greenland. in: Proceedings of the Fourth International Workshop on Mass Balance of the Greenland Ice Sheet and Related Topics. Held in Amsterdam, 22-24 Nov. 1993, Proceedings in press at the Greenland Geological Survey, Copenhagen.

Benson, C. S. and M. Sturm. 1993. Structure and Wind Transport of Seasonal Snow on the Arctic Slope of Alaska. Annals of Glaciology, Vol. 18 p.261-267.

Fahnestock, M., R. Bindschadler, R. Kwok, and K. Jezek. 1993. Greenland Ice Sheet Surface Properties and Ice Dynamics from ERS-1 SAR Imagery. Science, Vol. 262, p. 1530-1534.

Hall, D. K., C. S. Benson, and J. Y .L. Chein. 1993. Analysis of Visible and Microwave Satellite Data for Snow Mapping in Alaska. Proceedings of the 50th Annual

Eastern Snow Conference, 7-10 June 1993, Quebec City, Quebec, CANADA, p. 129-137.

Hall, D. K., C. S. Benson, and W. O. Field. 1994. Changes in Glaciers of Glacier Bay, Alaska using ground and Satellite Measurements. In preparation for a special issue on Alaskan Glaciers to be published in Physical Geography.

Hall, D.K., A.T.C. Chang, J.L. Foster, C.S. Benson, and W.M. Kovalick, 1989. Comparison of *in situ* and Landsat Derived Reflectance of Alaskan Glaciers. Remote Sensing of Environment, 28, 23-31.

Lingle, C. S., C. S. Benson, and T. K. Ahlnäs. 1994. Glacier Facies on Nabesna Glacier and Mt. Wrangell, Alaska, from Synthetic Aperture Radar (SAR) Data. Third Circumpolar Symposium on Remote Sensing of Arctic Environments, 16-20 May 1994, Fairbanks, Alaska.

Lingle, C. S., W. D. Harrison, T. K. Ahlnäs, T. A. Heinrichs, and J. J. Roush. 1993. Observation of Alaskan Glaciers with ERS-1 Synthetic Aperture Radar. in: SAR Users Meeting Abstracts. p. G1-G3. ASF-SAR Users Meeting 27-29 July 1993, Seattle, Washington.

Sturm, M., D.K. Hall, C.S. Benson, and W.O. Field, 1990. Glacier terminus fluctuations in the Wrangell and Chugach Mountains of Alaska resulting from non-climatic controls. International Conference on the Role of Polar Regions in Global Change. Proceedings of a conference held 11-15 June 1990 at the University of Alaska Fairbanks. Pages 519-523.

Sturm, M., D.K. Hall, C.S. Benson, and W.O. Field, 1991 Non-climatic control of glacier termini fluctuations in the Wrangell and Chugach Mountains of Alaska USA, Journal of Glaciology. Vol. 37, No.127 Pages 348-356.

Williams, R.S., D.K. Hall, C.S. Benson, 1991. Analysis of Glacier Facies Using Satellite Techniques. Journal of Glaciology, Vol. 37, No. 125, p. 120-128.